ASSESSMENT OF HAZARDOUS AREAS WHEN STORING HD 1.1 AMMUNITION IN FRENCH "IGLOO TYPE" MAGAZINE.

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ABSTRACT :

The French Army presently stores its ammunition inside" Igloo type" magazines, the unit capacity of which is 60 metric tons. Within the framework of pyrotechnical safety, the S.T.B.F.T. was asked by the Army Staff to determine by tests the extent of the hazardous areas related to this type of storage and to compare the results to the quantity distances (Q - D) selected in the French regulations.

The first phase of this test campaign, the subject of this paper, is only concerned with the assessment of Q - D related to blast effects (HD 1.1).

Twenty-one scaled tests (1 : 3) were performed in earth covered steel arch igloos. Different arrangements were tested in order to determine the influence of various parameters.

During the whole campaign, more than 300 blast pressure data were recorded, which enables to make an accurate comparison with the French regular Q - D and to add useful information to the numerous tests already performed in this area by other countries.

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I - INTRODUCTION :

As far as the pyrotechnical safety is concerned, French regulation specifications originate from the NATO AC 258 working group.

In particular, this group has determined the Q - D reductions to apply in case of explosion of HD 1.1 ammunition in an igloo type magazine.

Numerous tests and studies have already been performed in several countries, particularly in the United States and in the United Kingdom, in order to limit the extent of hazardous areas in that case.

The methodology adopted by the S.T.B.F.T. during these experiments is different in so far as the same tests were repeated several times in order to gather a lot of coherent data.

Moreover, some complementary tests were performed in particular conditions in order to determine the influence of various factors such as the loading rate and the environment near the donor.

Before giving the results, it seems important to recall briefly some specific points included in the French pyrotechnical safety regulations.

SITING RULES FOR FACILITIES

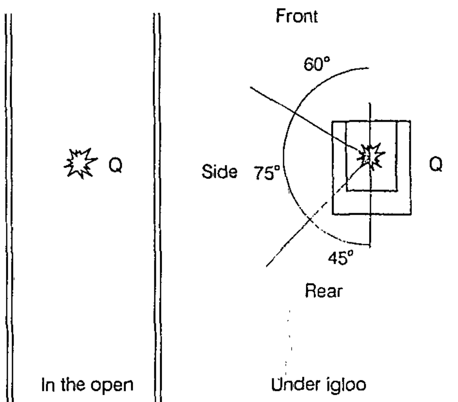
HAZARDOUS ZONES	PYROTECHNICAL ACCIDENT PROBABILITIES				
	P_1	P_2	P_3	P_4	P_5
Z1	a_0	a_0	a_0	a_0	a_0
Z2	a_1 a_2	a_1 a_2	a_1	a_1	a_1
Z3	$a_1 b_1 c_1$ a_2 a_3	$a_1 b_1 c_1$ a_2	a_1 a_2	a_1	a_1
Z4	$a_1 b_1 c_1$ $a_2 b_2 c_2$ a_3	$a_1 b_1 c_1$ $a_2 b_2 c_2$ a_3	$a_1 b_1 c_1$ a_2	a_1 a_2	a_1
Z5	$a_1 b_1 c_1$ $a_2 b_2 c_2$ $a_3 b_3 c_3$	$a_1 b_1 c_1$ $a_2 b_2 c_2$ $a_3 b_3 c_3$	$a_1 b_1 c_1$ $a_2 b_2 c_2$ $a_3 b_3 c_3$	$a_1 b_1 c_1$ $a_2 b_2 c_2$ $a_3 b_3 c_3$	$a_1 b_1 c_1$ $a_2 b_2 c_2$ $a_3 b_3$

Example:

Ammunition storage under igloo => P1
Inhabited bulding => category C3
=> authorized siting zone Z5

Table 1

HAZARD ZONES 1.1
FRENCH REGULATIONS



Zi :	P (bar)	Scaled distance (m/ kg $^{1/3}$)			
			Front	Side	Rear
Z1 :	> 0.6	5	5	5	5
Z2 :	0.3< P<0.6	8	8	8	8
Z3 :	0.1< P<0.3	15	15	15	12
Z4 :	0.05< P<0.1	22	22	18	14
Z5					

Table 2

II - SOME SPECIFIC ASPECTS OF THE FRENCH REGULATIONS :

The different installations to be protected against the effects of accidental explosion inside a pyrotechnical site are divided into three large categories, depending on their type and location in relation to the site:

- buildings or facilities inside the pyrotechnical site : category a.
- external public traffic routes : category b.
- buildings or facilities outside the pyrotechnical site : category c.

Table 1 indicates the allowable hazard level that is the potential location of the various categories of facilities mentioned above in every hazard zone defined as follows by :

- the pyrotechnical probability accident level selected,
- the category of building or facility considered.

Table 2 determines the extent of hazard zones HD 1.1 in case of open air burst or inside igloo burst as well as the incident pressure level expected at the boundaries of each zone.

These scaled distances are the prescriptive figures to which the experimental data have been compared.

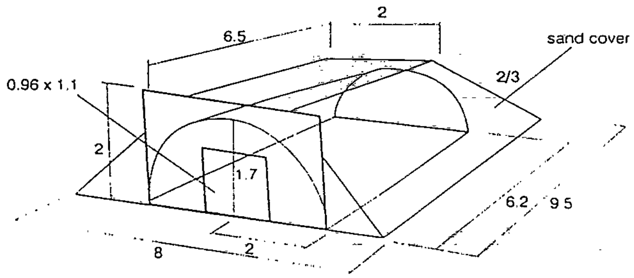
In spite of some specific aspects, the French selected Q - D for free air burst(8 $Q^{1/3}$ - 15 $Q^{1/3}$ and 22 $Q^{1/3}$) are roughly in agreement with Explosive Workshop, Public Traffic Route and Inhabited Building Distances (EWD, PTRD, IBD) mentioned in the NATO regulations.

III - TRIALS SPECIFICATION :

All tests were carried out at 1:3 scale.

31 - Donor characteristics :

During the whole campaign, only one type of donor was used. It was a metal arch sand covered structure, the main characteristics of which can be seen in figure 1. The size of the donor and its sand mound were reduced to 1:3 scale compared with the actual igloo containing 60 metric tons, which can be built with metal or reinforced concrete.



	Scale	Q kg	Loading kg/m3 density	Aspect w/l ratio	Details
L W	1/3	2900 2200	87 66	0.3	Single bay steel arch igloo e=10mm H x W x L 1.7 x 4 x 6.2m V= 33.1m³ Minimal thickness of sand (apex) 0.3m

Fig 1

32 - Configuration of tests :

(Table 3)

22 tests were performed, 21 were selected. One of them was not taken into account because of incoherent data.The location of the donor igloo was modified for every test.

Most of explosive trials were conducted under isolated igloos.However, 6 trials were carried out under igloos which were partially or totally surrounded by sand mounds simulating adjacent igloos in order to determine their potential influence on the extent of the first hazard zones in the vicinity of the donor.

In these cases, the distances between the donor and its neighbors were fixed to 0.5 $Q^{1/3}$ side to side and 0.8 $Q^{1/3}$ rear to front according regulation specifications.

33 - Explosive charges involved :

According to the available stocks two types of ammunition were used for the composition of 2.2 ton charges which represented 60 metric tons full size .

- Charge n° 1 : composed with 164 snake demolition M3 cartridges (13.5 kg TNT equivalency per cartridge).
- Charge n° 2 : composed with 44 Benoto torpedoes (50 kg TNT equivalency per torpedo).

In fact, the TNT equivalent weight of the American ammunition had been underestimated. Specific tests revealed thar the real TNT equivalent weight of a cartridge was about 17.5 kg.

Finally, the two types of charge used represented respectively 2.2 tons (60 tons full size) and 2.9 tons (78 tons full size).

These orthorombic shape charges were placed at the center of the donor and were ignited in two points on the opposite of the headwall.

SCOPE OF THE TESTS

Experimental set-up	Charge weight (Tons)	Quantity of tests	Quantity of reliable pressure data
DONOR separate	2.9	13	191
	2.2	2	47
DONOR partially surrounded	2.9	4	66
DONOR surrounded	2.9	2	34
TOTAL		21	338

Table 3

LOCATION SCHEMES FOR PRESSURE GAGES

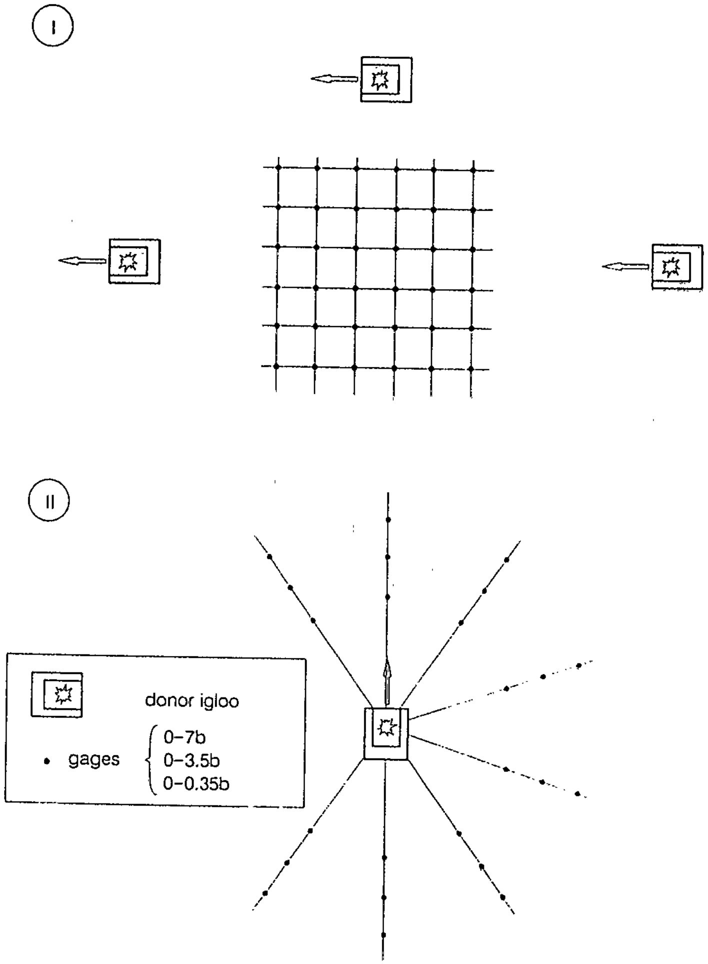


Fig 2

34 - Measurements of blast parameters :

- Pressure :

The pressure measurements were recorded by various range piezoelectric gages depending on their situation away from the donor.

- 0 - 7 bar (0 - 100 psi)
- 0 - 3.5 bar (0 - 50 psi)
- 0 - 0.35 bar (0 - 5 psi)

These gages were located according to different lay-out schemes (fig. 2).

At the beginning, a fixed grid was placed and the data recorded in the different directions were achieved by the donor displacement.

Then in order to outline the isobaric plot 0.05 b the gages were placed radially.

- Impulses :

As the French regulations do not explicitly refer to impulse levels expected at the different hazard zone boundaries, these ones were not considered.

35 - Additional surveys :

The whole tests were covered by high speed and video cameras.

Aerial surveys were performed in order to investigate the shape and the size of the craters.

Finally the location of some debris of the donor which could be easily identified was surveyed, in particular the initial sheet of the donor rear and front walls.

IV - RESULTS PRESENTATION :

For each direction considered, the recorded values were plotted on log-log graphs including the Kingery curve and the step fonction which corresponds to the regular Q - D specifications.

Three series of curves were plotted :

- 1st series : 2.2 metric ton charges.
- 2nd series : 2.9 metric ton charges.

In the 3rd series the curves of 2.2 and 2.9 ton charges were gathered.

In order to get a clear picture only the 3rd series of curves is shown in figures 3a - 4a - 5a. The mean curves derived from the distributed points may be equated by :

- front : $p = 5.82\ x^{-1.64}$
- side : $p = 5.31\ x^{-1.63}$
- rear : $p = 4.03\ x^{-1.55}$

with : p expressed in bar (10^2 kPa)

x : scaled distance expressed in $m/kg^{1/3}$.

The experimental Q - D values have been derived from these equations for pressure levels applied at the hazard zone boundaries and compared with Q - D values mentioned in the French regulations (fig. 3b - 4b - 5b).

Simultaneously with these experimental mean values, maximal values corresponding to the envelope curves were determined (Table 4). In order to be conservative while taking into account the scatter of results it seemed to be suitable to neglect 5 % of the highest pressure data.

Finally these experimental values selected were compared to the regular Q - D

- for under igloo bursts (table 6 + fig 6),
- for open air bursts (table 7 + fig 7)

V - INTERPRETATION OF RESULTS :

51 - Influence of various factors :

• Loading rate of the donor

Studies led in the framework of the AC 258 working group have tried to determine the influence of this parameter on the quantity distances to be considered.

The two loading rates tested during this campaign, 66 kg/m^3 and 87 kg/m^3 did not reveal a substantial difference in the quantity distance values experimentally obtained. This observation has enabled to gather the results of both explosive charges tested in the same group.

* Donor environment

This factor has no significant influence for scaled distances higher than 5 $Q^{1/3}$. At short range, the igloos in the neighborhood of the donor seem to alter the blast pressure level within a range of about 20 %. This increase or decrease depends on the measure point in relation with the donor.

Nevertheless, this 20 % variation should not be overrated since an important scatter of results is always observed at short range however cautious one may have been to perform tests in similar conditions.

52 - Comparison with Q - D regular values :

Generally, the whole experimental results seem to be fairly coherent if we consider the relative positions of the mean values in relation with the Kingery curve.

Morever, for a given pressure level the highest experimental Q - D values are always found in the front direction while the lowest are in the rear one.

When these values are compared with the regular onesin case of accidental explosion under igloo it must be noted that :

- on the front : the experimental results are always lower than the prescriptive values (about 7 %). This can be explained by the fact that, for this direction regular Q - D are the same for open air and under igloo bursts.
- on the contrary, as far as the side and mainly rear directions are concerned the reductions prescribed in the regulations seem too high : for example on the rear face the experimental value for IBD exceeds the regular value by more than 20 % (17 $Q^{1/3}$ instead of 14 $Q^{1/3}$).

	Z1	Z2	Z3	Z4	Z5
P(bar)	0.6	0.3	0.1	0.05	
FRONT					
Mean value (1)	4	6.1	11.9	19.7	
Maximum value (2)	4.7	8.9	15.5	22.5	
Selected value (3)	4.5	8	14	20.5	
SIDE					
Mean value (1)	3.8	5.9	11.9	17.4	
Maximum value (2)	4.2	7.5	15.2	20	
Selected value (3)	4.1	6.6	13.5	18	
REAR					
Mean value (1)	3.4	5.3	10.8	15.8	
Maximum value (2)	3.6	6.2	13.6	18.5	
Selected value (3)	3.5	5.9	13.1	17	

(1) Regression curve

(2) Envelope curve

(3) The 5% most extreme data points not considered

Table 4

This experiment has revealed a comparatively small distorsion between the front and the rear Q - Ds :

$$\frac{Q - D \text{ Front}}{Q - D \text{ Rear}} = 1.2 \quad \text{(average value).}$$

We may infer that the igloo metal type and its arch shape have slighty reduced the confinement level of the explosion. This could partially explain the relatively high rate of energy dissipated in the rear direction.

VI - CONCLUSION :

Certainly, these scale tests performed in metal structures have specific configurations.

Nevertheless, these series of trials give additional information to the whole studies which have been conducted in several countries for the past 20 years in order to define more accurately the extent of hazard zones resulting from accidental explosion in a storage igloo.

Other types of hazard are still to be assessed, mainly those which are caused by fragments and debris . This question should be examined in future trials.

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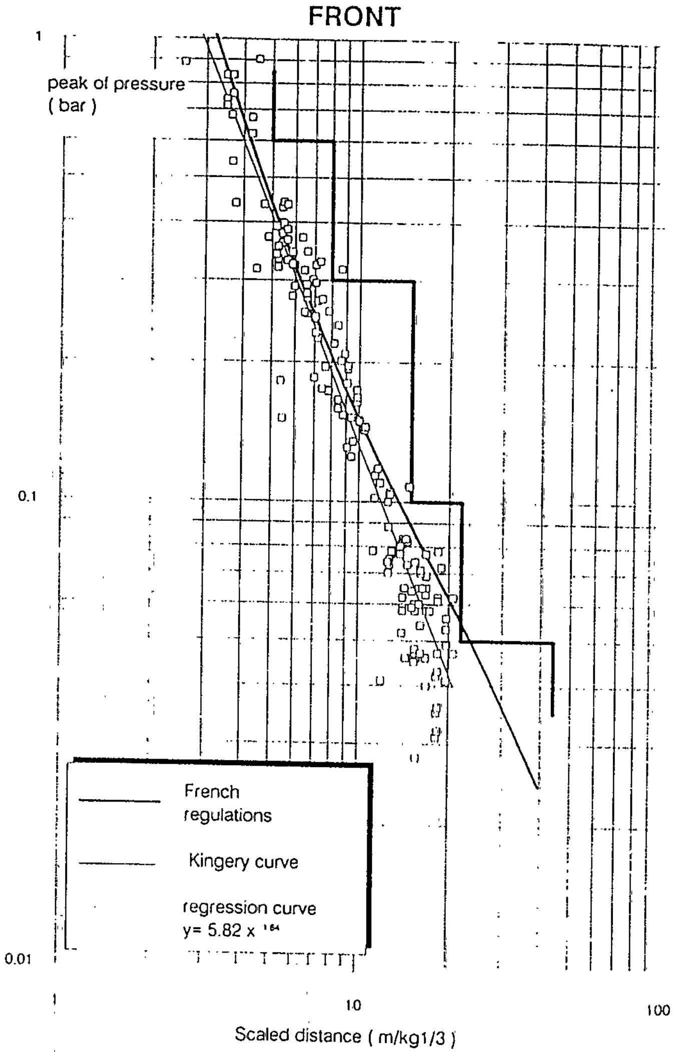
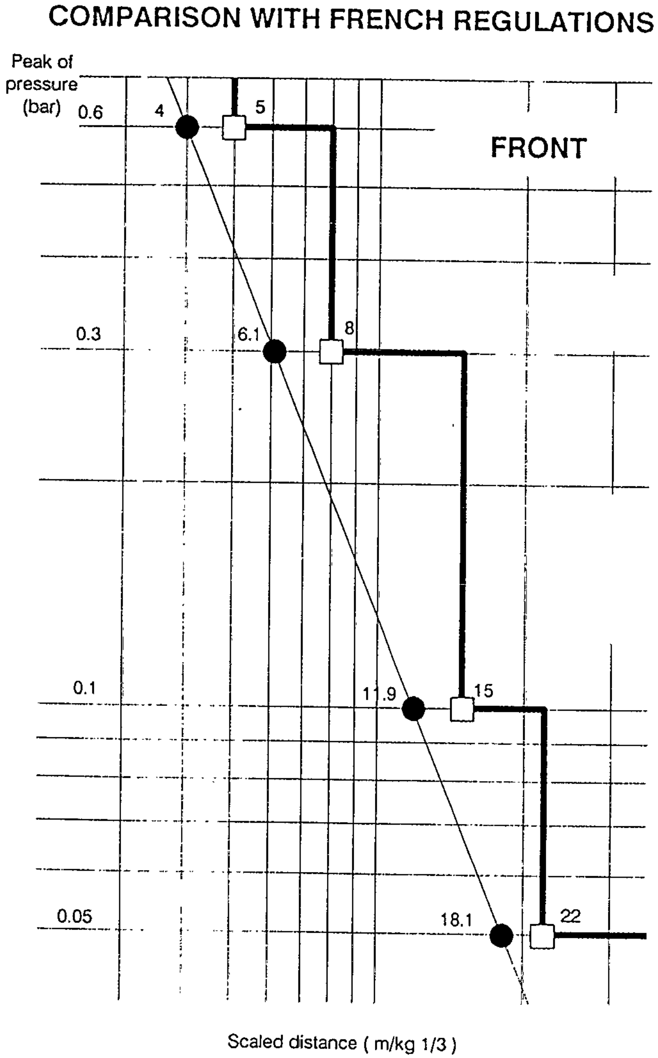


FRONT
peak of pressure
(bar)
1
0.1
0.01
French
regulations
Kingery curve
regression curve
y= 5.82 x ⁻¹·⁶⁴
1
10
100
Scaled distance (m/kg1/3)

Fig 3a



COMPARISON WITH FRENCH REGULATIONS
Peak of
pressure
(bar)
0.6
0.3
0.1
0.05
4
5
6.1
8
11.9
15
18.1
22
FRONT
Scaled distance (m/kg 1/3)

Fig 3b

COMPARISON WITH FRENCH REGULATIONS

SIDE

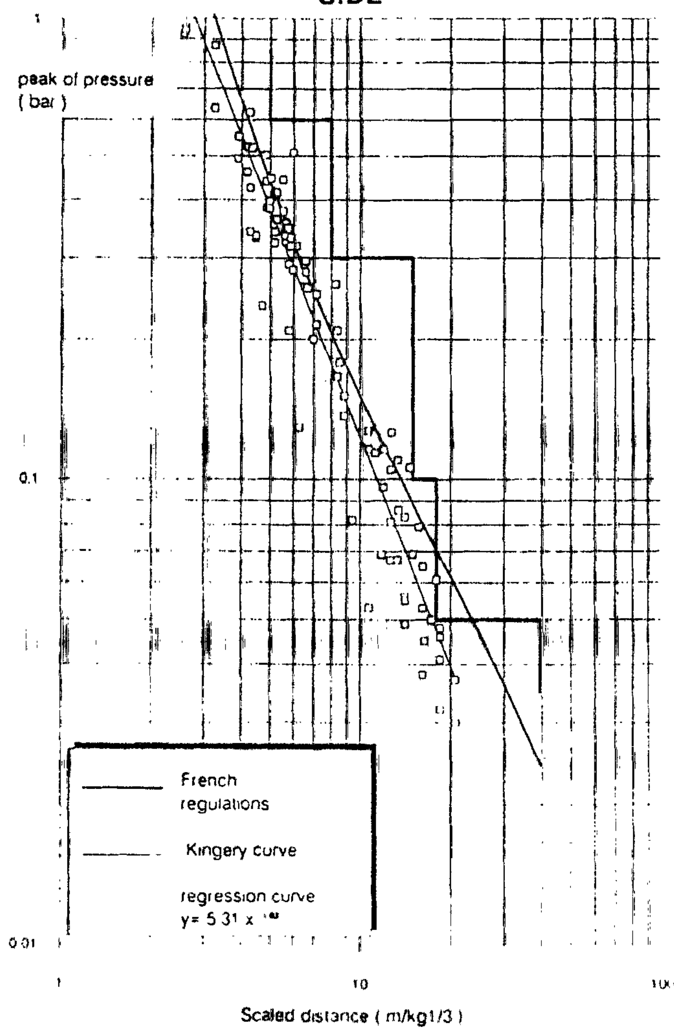


Fig 4a

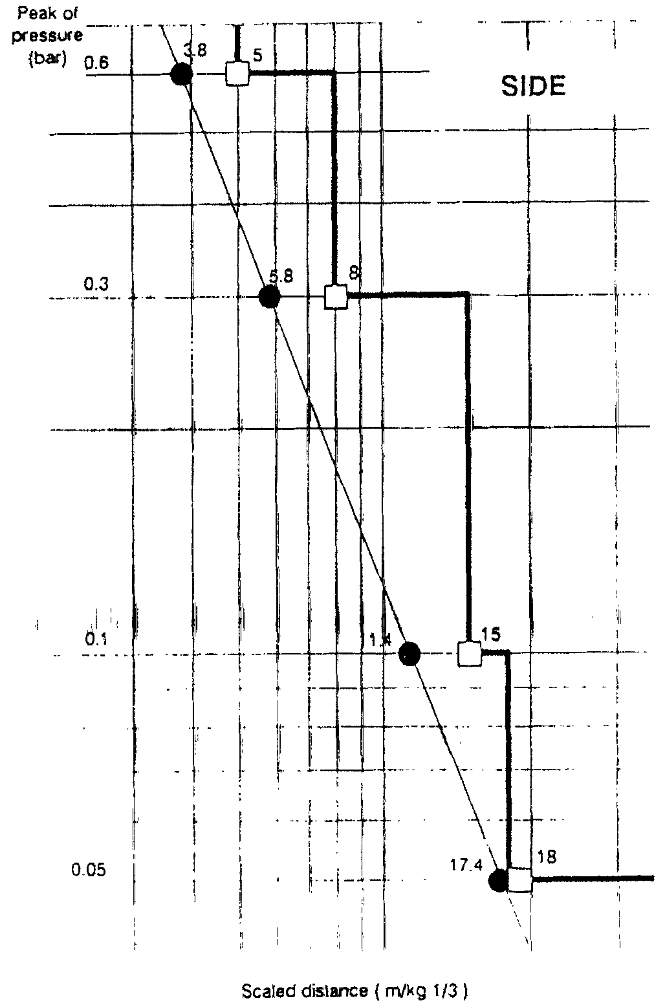


Fig 4b

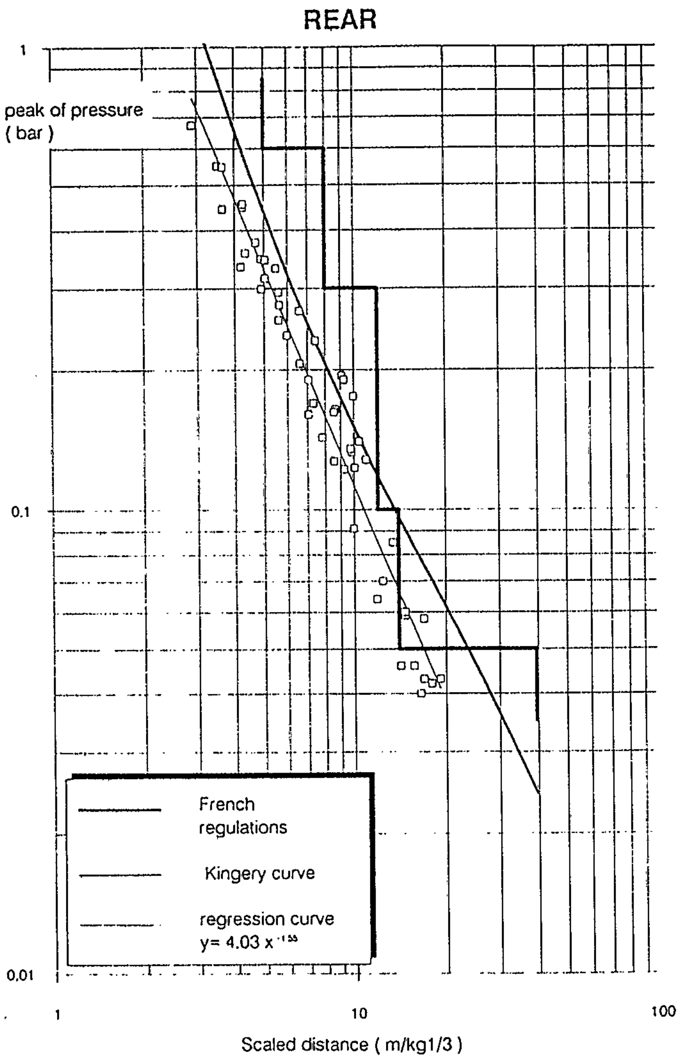


Fig 5a

COMPARISON WITH FRENCH REGULATIONS

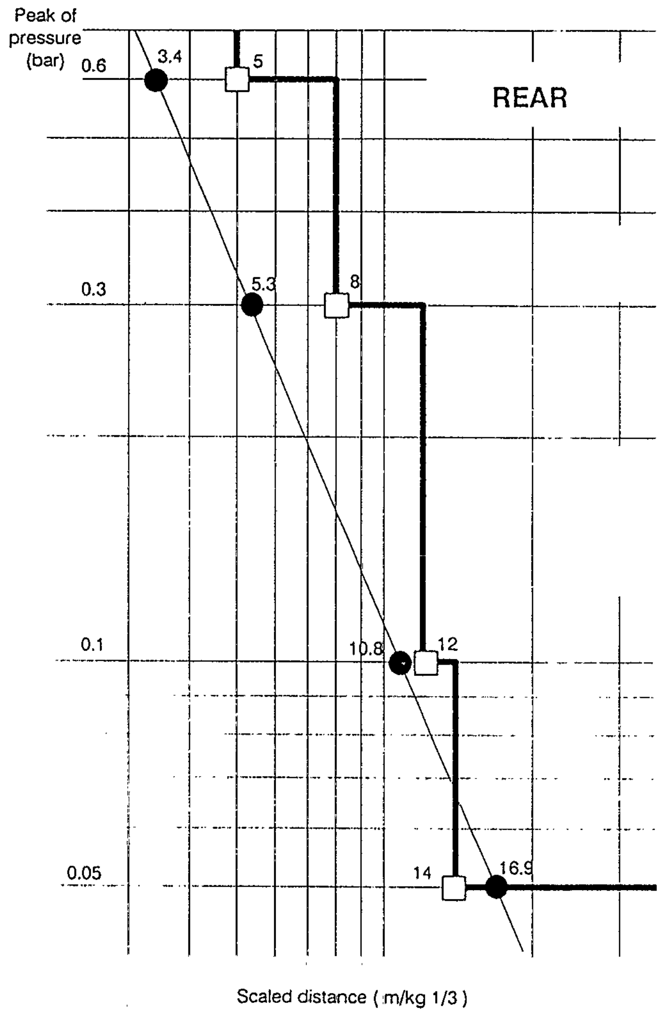


Fig 5b

COMPARISON WITH Q–D REGULAR VALUES
(Under Igloo)

	Z1	Z2	Z3	Z4	Z5
P (bar)	0.6	0.3	0 1	0 05	
FRONT					
Regulations value	5	8	15	22	
Trials Result	4.5	8	14	20.5	
% Reduction (–) Increasing (+)	- 10%	0%	- 7 %	- 7 %	
SIDE					
Regulations Value	5	8	15	18	
Trials result	4.1	6.6	13.5	18	
% Reduction (–) Increasing (+)	- 18 %	- 17 %	- 10 %	0 %	
REAR					
Regulations value	5	8	12	14	
Trials result	3 5	5 9	13 1	17	
% Reduction (–) Increasing (+)	- 30 %	- 26 %	+ 9 %	+ 21 %	

Table 6

COMPARED SCALED RANGE FOR IBD

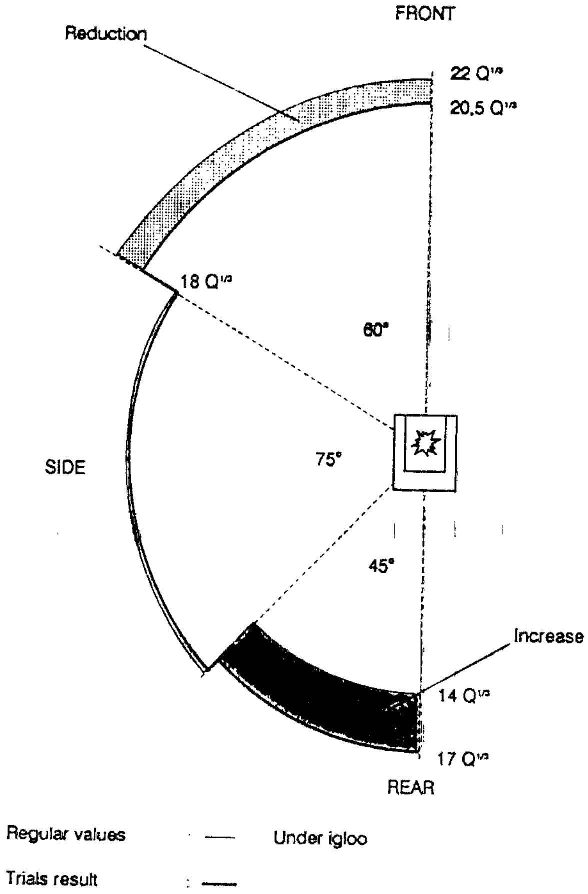


Fig 6

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COMPARISON WITH Q–D REGULAR VALUES (In the open air)

ZONE	Z1		Z2		Z3		Z4		Z5
P(bar)		0.6		0.3		0.1		0.05	
Regulations Value		5		8		15		22	

FRONT

Trials result	4.5	8	14	20.5
% reduction (–)	– 10 %	0 %	– 7%	– 7%

SIDE

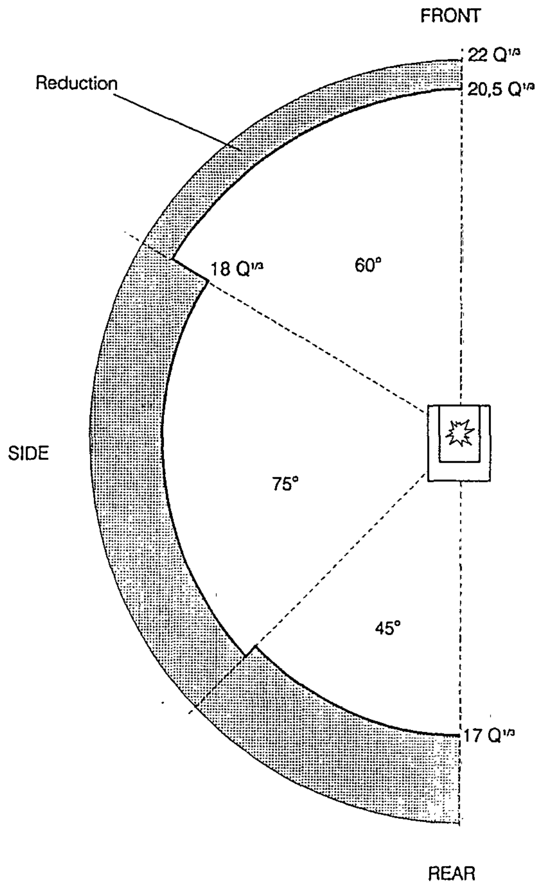
Trials result	4.1	6.6	13.5	18
% reduction (–)	– 18 %	– 17 %	– 10 %	– 18 %

REAR

Trials result	3.5	5.9	13.1	17
% reduction (–)	– 30 %	– 26 %	– 12 %	– 22 %

Table 7

COMPARED SCALED RANGE FOR IBD



Regular values : —— In the open air

Trials result : ——

Fig 7